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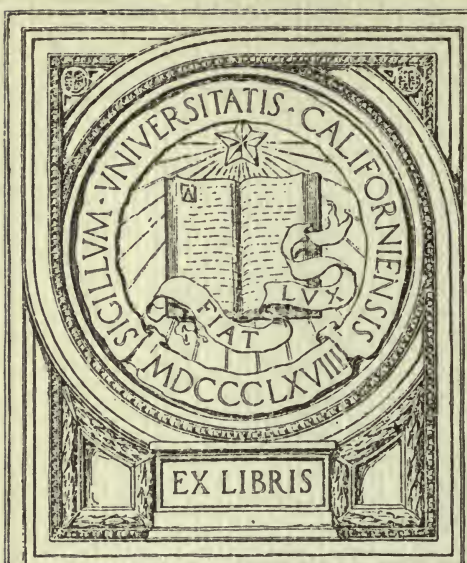

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NEW SERIES.

Agricultural Students' Gazette.

VOL. VII. APRIL, 1895. No. 3.

UPON SOME PROPERTIES OF SOILS,

WHICH HAVE GROWN A CEREAL CROP AND A LEGUMINOUS CROP FOR MANY YEARS IN SUCCESSION.

By SIR JOHN BENNET LAWES, Bart., F.R.S., &c.

The field upon which our experimental wheat crops are grown is irregular in shape, and the area of the twenty-two experiments for some years differed slightly one from the other, rendering it necessary to make a separate calculation for each in order to bring it into acreage. During the year 1882, thirty-nine years after the commencement of the experiments, it was decided to make the area of all the plots equal, which was done by cutting off a portion of the experimental field at the top and bottom. It is well known that the success of our experiments has greatly depended upon keeping the land as free as possible from weeds, in order that the wheat plants should have to themselves all the food in the soil, and I was very anxious to know what sort of a fight the wheat would make against any vegetation which might spring up if the crop were no longer kept free from weeds by manual labour. Accordingly, instead of cutting the crop upon the portion of land at the top and bottom of the field which would cease to be under experiment, it was left standing to shed its seed for another crop; so that the whole crop, which in some of the experiments would be over 30 bushels per acre, would be deposited in the land instead of only the two bushels of seed which were sown per acre upon the other portions of the field. The result of this experiment may be summed up in a very few words. Before the next harvest the indigenous vegetation had taken possession of the land to such an extent that nothing to be called a crop was grown in any of the experiments, and in the second and third year the wheat was represented by a few straggling plants which had but a faint resemblance to their original parents; some of the plants had only one or two small seeds in the ear and the thin stalks were not the least like the straw of wheat. Specimens of the wheat when left to seed itself, with the straw, and a year or two afterwards, are placed in the Museum of the College.

A reproduction of a photograph to life size of two of the ears of corn for each of the years 1883, 1884, and 1885, accompanies this paper.

In July, 1886, four years after the top and bottom of the field had been left undisturbed, a careful examination of the vegetation was made by Mr. Willis, and the following is his report—"Seventeen orders of

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plants are represented, being composed of thirty-eight genera and forty species." Particulars of these are given in the following table :—

ROTHAMSTED.

Experiments on Wheat, 43 years in succession on the same Land.

List of Plants observed July 27th, 1886, growing on portion of ground left to seed itself and uncultivated since Harvest, 1882.

Botanical Order.	Botanical Name of Plant.	Degree of Prominence.
Gramineæ	Agrostis vulgaris, var. alba	Exceedingly abundant
	Alopecurus agrestis	Plentiful
	Phleum pratense	Occasional
	Poa trivialis	Moderate amount
	Holcus lanatus	Occasional
	Cynosurus cristatus	Scarce
	Dactylis glomerata	Scarce
Leguminosæ	Medicago lupulina	Very abundant
	Lathyrus pratensis	Frequent
	Trifolium repens	Frequent
	Trifolium pratense	Rare
	Ervum hirsutum	Rare
Ranunculaceæ	Ranunculus repens	Occasional
Violarieæ	Viola tricolor	Scarce
Caryophylleæ	Cerastium vulgatum	Frequent
Umbelliferæ	Æthusa Cynapium	Frequent
	Heracleum sphondylium	Occasional
	Caucalis infesta	Frequent
Rubiceæ	Galium tricorne	Occasional
Dipsaceæ	Scabiosa arvensis	Occasional
Compositæ	Sonchus arvensis	Occasional
	Sonchus oleraceus	Scarce
	Taraxacum Dens leonis	Frequent
	Carduus arvensis	Frequent
	Gnaphalium uliginosum	Occasional
	Tussilago Farfara	Plentiful
	Bellis perennis	Rare
	Anthemis Cotula	Occasional
	Centaurea nigra	Rare
	Lapsana communis	Plentiful
Convolvulaceæ	Convolvulus arvensis	Plentiful
Scrophularineæ	Veronica agrestis	Scarce
	Bartsia odonites	Frequent
Borragineæ	Myosotis arvensis	Frequent
Labiatæ	Stachys sylvatica	Rare
	Prunella vulgaris	Scarce
Primulaceæ	Anagallis arvensis	Occasional
Plantagineæ	Plantago lanceolata	Rare
Euphobiaceæ	Euphorbia exigua	Frequent
Equisetaceæ	Equisetum arvense	Plentiful

In the Autumn of 1894 the ground was again carefully examined by Mr. Willis, when he found twenty-one different orders of plants, which were composed of forty-six genera and fifty-one species, consisting of twenty-two annuals, two biennials, and twenty-seven perennials. A list of the plants observed is given on the opposite page.

The Leguminous species have spread most wonderfully ; particularly Lathyrus pratensis, which annually yields abundance of seed. Young oak and ash trees, hazel, rose and hawthorn bushes are also to be found upon the upper portion near the hedge. It would be exceedingly interesting to know what peculiar properties the soil had acquired during this long period of cereal growth to cause such a variety of plants to find food suitable for their growth. The extreme luxuriance of the leguminous plants is especially to be noticed. The soil of our

List of Plants now (1895) growing on portion of ground left to seed itself, and uncultivated, since Harvest, 1882.

Orders.	Botanical name of Plant.	English or Common name.	Notes upon the degree of prominence since 1886.
Gramineæ	Agrostis vulgaris, var. alba	Marsh Bent Grass	Exceedingly abundant, increasing in quantity
	Alopecurus agrestis	Slender Fox Tail	Plentiful, upon the whole going down
	Alopecurus pratensis	Meadow Fox Tail	Occasional
	Phleum pratense	Cats-tail Grass	Occasional, dying out
	Poa trivialis	Rough Stalked Meadow Grass	Moderate amount, maintains its position
	Poa pratensis	Smooth Stalked Meadow Grass	Occasional
	Holcus lanatus	Soft Woolly Grass	Occasional, keeps its ground
	Cynosurus cristatus	Dogs-tail Grass	Scarce, dying out
	Dactylis glomerata	Cock's Foot	Moderate, rather increasing
	Bromus mollis	Soft Brome Grass	Scarce
Leguminosæ	Medicago lupulina	Black Medick	Very abundant, increasing rapidly both at Top and Bottom
	Lathyrus pratensis	Meadow Pea : Vetchling	Abundant, increasing rapidly, especially at Top
	Trifolium repens	White Clover	Frequent, spreading
	Trifolium pratense	Red Clover	Rare, inclined to die out
	Ervum hirsutum	Hairy Tare	Occasional, increasing slowly
	Lotus corniculatus	Bird's Foot Trefoil	Rare
Ranunculaceæ	Ranunculus repens	Creeping Buttercup	Occasional
Violarieæ	Viola tricolor	Field Hearts Ease	Scarce, dying out
Caryophylleæ	Cerastium vulgatum	Broad Leaved Mouse Ear Chickweed	Occasional, dying out
	Stellaria media	Common Stitchwort	Occasional
Polygoneæ	Polygonum aviculare	Iron Grass	Moderate, increasing
Umbelliferæ	Æthusa Cynapium	Fool's Parsley	Occasional, dying out
	Heracleum Sphondylium	Hog Weed	Occasional, increasing, especially at Top
	Caucalis infesta	Spreading Hedge Parsley	Occasional, dying out
Rubiaceæ	Galium tricorne	Corn Bed Straw	Scarce, dying out
	Galium aparine	Cleavers	Scarce
Dipsaceæ	Scabiosa arvensis	Field Scabious	Occasional, increasing at the Top
Compositæ	Sonchus arvensis	Corn Thistle	Moderate, increasing at Top
	Sonchus oleraceus	Sow Thistle	Scarce
	Taraxacum Dens leonis	Dandelion	Frequent, spreading
	Carduus arvensis	Creeping Thistle	Frequent, increasing rapidly
	Gnaphalium uliginosum	Marsh Cudweed	Scarce, dying out
	Tussilago Farfara	Coltsfoot	Plentiful, increasing
	Bellis perennis	Daisy	Rare, dying out
	Anthemis Cotula	Stinking Chamomile	Scarce, almost gone
	Centauria nigra	Hard Head ; Knapweed	Occasional
	Lapsana communis	Nipplewort	Moderate, rather decreasing
	Senecio Jacobeæ	Common Ragwort	Occasional, increasing, particularly at Top
Convolvulaceæ	Convolvulus arvensis	Small Bindweed	Occasional
Scrophularineæ	Veronica agrestis	Field Speedwell	Scarce
	Bartsia odonites	Red Bartsia	Scarce, dying out
Boragineæ	Myosotis arvensis	Field Scorpion Grass	Occasional, inclined to die out
Labiatæ	Stachys sylvatica	Hedge Stachys	Rare, dying out
	Prunella vulgaris	Self Heal	Scarce
Primulaceæ	Anagallis arvensis	Pimpernel	Scarce, dying out
Plantagineæ	Plantago lanceolata	Narrow-leaved Plantain	Occasional, increasing
Euphobiaceæ	Euphorbia exigua	Dwarf Spurge	Occasional, dying out
Equisetaceæ	Equisetum arvense	Corn Horse Tail	Moderate, increasing
Chenopodeæ	Atriplix patula	Orache	Scarce
Urticeæ	Urtica dioica	Common Nettle	Scarce
Papaveraceæ	Papaver Rhœas	Red Poppy	Rare

wheat field has been carefully sampled and analysed from time to time, and it is very probable that when the soil at the top and bottom of the field is examined we shall find some increase in the nitrogen, which would probably be due to the action of the leguminous plants; the soil, however, must have acquired properties which are not to be ascertained by ordinary chemical analysis alone, and might afford an interesting study for those who investigate the minute organisms which play so important a part in animal and vegetable life.

I will now describe an experiment very similar to the last, in which a field which had been growing a leguminous crop for a great number of years, was allowed to cover itself with native vegetation. In 1848 it was decided to grow continuous crops of beans under circumstances with regard to manure, &c., very similar to the experiments upon wheat; it was, however, found that this crop when continuously grown could not be depended upon under any system of cultivation, and after more than thirty years of very unsatisfactory results, it was decided to give up the experiment. The unmanured bean land would hardly yield a crop equal to the seed sown. Barley and red clover were then taken, but the barley was much injured by the immense growth of the clover amongst it which yielded large crops during the two following years. A considerable part of the field was then turned into the park for permanent pasture; but about two acres were fenced off so as to prevent any stock going upon it; and for the last ten years it has been allowed to grow native vegetation without disturbance of any kind. Round three sides of the field there are high hedges with a good many trees growing in them; on the fourth side iron hurdles separate it from the permanent pasture. I should say that this piece of land is more favourably situated for the growth of a great variety of native vegetation than the wheat field, and yet none has come upon it. The vegetation consists of a few tall, tufted growing grasses; and near one oak tree there are a few small oak trees due to the unconsumed acorn stores of mice. Along the line of hurdles which separates the bean land from the pasture there is abundance of white clover, but none crosses the border. Nothing can be less interesting than the vegetation of this field, or more remarkable as contrasted with that of the wheat field; a result which was not anticipated, and which at present remains unexplained. When we sow one half of a field with corn and see flocks of birds of all descriptions settled there, while none are to be seen upon the unsown portion, we know that the birds find their food on one part of the field and not on the other; here we have two fields treated exactly alike for long periods of time; some portions unmanured, some receiving farm-yard manure, minerals only, nitrates, ammonia, &c.; the only difference being that one has grown a cereal, the other a leguminous crop; and yet, when put out of cultivation, in one field great varieties of native vegetation find their appropriate food, while in the other only one is to be found; we know that the birds are attracted by the corn sown, but what attracts the vegetation? In our rotation experiments, published last year in the Journal of the

Royal Agricultural Society, there are two sets resembling each other in every respect but one; two are grown upon land kept entirely without manure; two are manured with minerals, and two are highly manured; the only difference between the two sets is, that upon one we have a leguminous crop (beans or red clover) once in four years, while upon the other we have a summer fallow. Thus, therefore, for a period not much short of half a century no leguminous crop has been grown on the latter portion of the experiments. Some years ago a few scattered plants of yellow trefoil were seen amongst the barley on that portion which had grown no leguminous crops. It would have injured the barley if men had been sent in to pull them out, and it was considered that as there would be a summer fallow in the following year the seed would germinate and be destroyed; at all events as we should have a root crop before we took another barley crop, the fine tilth required for the roots and the constant horse and hand hoeing would secure the germination and destruction of every trefoil seed: such, however, was not the case. Whether "an enemy" had sown the seed, or whatever the cause, the trefoil came up thicker than ever, especially upon the highly manured portions of the field, and it was found to be a very serious and expensive undertaking to get rid of this little pest. It is quite evident that when the land is kept free from leguminous plant-growth, matters accumulate in the soil which are highly favourable to these plants. This is seen both in the experiment just described and in the top and bottom of our wheat field. It is tolerably certain that the matter accumulated does not consist of ordinary manure ingredients, because we cannot grow a leguminous crop continuously by the use of them, as was seen in the bean field: important and interesting investigations could be made on this subject.

In the rotation experiments it was shown that after the first root crop was removed from the unmanured land no further root crops could be grown; the plant even ceased to form a bulb. Upon the same unmanured soil both barley and wheat have produced good crops, and in all probability will continue to do so for a very long period of time. The special property of the cereal crops to obtain their food and to continue their growth on the same soil, when plants of other orders fail to do so, appears to be a most important fact when we consider that in some form or other these crops furnish the bulk of the food of the whole world. I am disposed to think that if we could have in succession the climate, that is, the temperature, rainfall, &c., suitable to the various food crops of the world, rice, sugar-cane, maize, &c., they would, if grown upon our wheat field, give results very similar to those we obtain in the growth of wheat; growing largely increased crops when manured by the same manures, which now increase our wheat crops, and growing continuously without any manure whatever. It has sometimes been suggested that a piece of land which has received no manure for fifty-five years and has grown an average crop of wheat equal to, if not larger than the average crop of the world, must possess some remarkable store of fertility; I propose therefore to imagine what

might be the possible history of this field in remote times, what was its original fertility, what it has lost of its fertility, and also what it has lost during its half-century of wheat growing. I do not intend to take any notice of those important ingredients in the soil, phosphoric acid and potash, because they exist in much larger quantities than nitrogen; and also because we have the evidence that when salts of ammonia have been applied to one of the plots which have received no mineral manure since 1844, the crop has been all along and is at the present time larger than the crops which has been manured every year with minerals only.

The history of the field as far back as we have any absolute record begins in 1623, when a map of that date gives the area of the field, and the hedges as they are at the present time. It was then in arable cultivation and had a broad band of grass round three sides, with a still broader piece of grass at the bottom; hence probably its name of "Broadbalk." It is by a comparison between the composition of the pasture and the arable part of this field that I propose to get some idea of the original composition of the soil; but although we have evidence that the exhaustion of the land by continuous wheat crops takes place in the first, second, and third nine inches from the surface, I only intend to refer to the first nine inches. The determination of the nitrogen in the soil of the wheat field was made as early as 1846, but the figures are not to be depended on, as at that time we did not possess the accurate mode of sampling the soil which we employ later on. For the purpose of my present paper I will make use of the analyses which were made in 1865 and again in 1881. The quantity of nitrogen per acre upon the upper nine inches of the soil of the unmanured land amounted to 2,507 lbs. and 2,403 lbs., showing a loss in sixteen years of 104 lbs., or between 6 and 7 lbs. per acre per annum. The nitrogen in the first nine inches of the pasture at the bottom of the field amounts to 6,200 lbs. per acre; and this amount does not differ very much from that contained in the permanent pasture of the park or of a meadow close to the wheat field. Even if we had not the actual evidence as to the field having been in arable cultivation in 1623 we should have no difficulty in deciding that such was the case; for knowing what we do of the farming of that period it would be impossible to attribute to any other cause such a loss of nitrogen as has taken place since then. The history of agriculture at very early periods gives us very little assistance in endeavouring to trace what would be the character of a soil when it was first taken into arable cultivation. Broderick, in his work upon English land and English landlords, tells us that the soil of England had been very little disturbed by the plough before the invasion of Julius Cæsar; and he says further on, "the practice of agriculture was an instinct and a tradition among the bodies of settlers who formed Roman colonies, nine at least of which were established in Great Britain." During the first four or five hundred years of the Christian era, when the Romans occupied this country, their chief city was "Verulanium," now St. Alban's. Possibly the site might have

been selected on account of the character of the soil; at all events, when draining was unknown and manure not used it might be considered that a bed of clay upon chalk would be the most suitable soil to select for the growth of corn. I think, therefore, that the land in this district, only four miles from St. Albans and within one mile of a great Roman road, would very early be selected for this purpose. Unfortunately we do not know what was the actual process of Roman agriculture; we may, however, assume that two or more corn crops were grown, and that then the land was left to recover its fertility by the growth of weeds At all events this was the process adopted several centuries afterwards, for Broderick describes the agriculture of the middle ages as consisting of a crop of barley, oats, or beans, followed by a crop of wheat, and then rest; the crop of wheat from two bushels of seed giving eight bushels. Not very long after the Conquest the manor of Rothamsted was granted, although to whom I do not know; but that it was a very extensive one may be seen by the large number of copy-holders upon the Court-rolls. Where there was a manor there would be a manor house, and although there may have been several before the present one was built, the oldest part of which dates from the time of Edward IV., there is some evidence to show that they stood upon, or not far from the present site; the woods, the hedges, the fields being very little changed from what they were nearly three hundred years ago, when the property came into the possession of my family. But the question I should like to be able to solve is, What was the nature, the composition of the soil when the first crop of wheat was grown upon it, perhaps fifteen or eighteen hundred years ago? Although we know something about the timber which was indigenous to Great Britain as distinguished from the trees which were brought over from other countries, I fear the same cannot be said of the native vegetation which covered our fields. Was the deep-rooted *lotus* or the creeping *lathyrus* a native? As far as I can form an opinion, the land in this district was employed for corn growing at a very early date; that it went through periods of cultivation and rest; and that although the soil would be deprived of both phosphoric acid and potash, I do not think that the nitrogen which it contained would be more than that which we find in the present pasture, and probably not so much. Whether the soils resting upon the chalk were or were not in arable cultivation during the Roman occupation, it is quite certain that they have been cultivated with corn crops for a great many centuries; and if exhaustion of the soil had been possible very little fertility would be left in them. When therefore the term "exhaustion" is used in agriculture it must be understood to refer not to the condition of the land itself but to those ingredients which one farmer puts in the soil and another removes.

In conclusion, I may point out that however erroneous my views may be with regard to the original fertility of my soil, the fact cannot be ignored that the exhaustion under continued wheat crops without manure has been very slow. Eighteen bushels per acre were grown in

the favourable season of 1894, the last manure applied to the land being fifty-five years ago. Owing to a succession of unfavourable seasons between 1871 and 1883, the average yield of the unmanured land was lower than it has been during the last ten years. Still there is a gradual decline in the crop going on; and if the seasons were always exactly alike instead of being widely different, we might expect to find this decline exactly the same each year. As I before remarked, the property which the cereal crops possess of obtaining their food from an unmanured soil over very long periods of time, while root and leguminous crops fail to do so, points them out as specially suitable for furnishing the human race with the greater portion of their food. In addition to this property they can be increased very largely and with great certainty by the application of ordinary or artificial manures. If, as appears to be probable, it is further proved that during the exhaustion due to the long continued growth of cereal crops fertility can be restored and a fresh series of corn crops be taken, we see why the exhausted soil of one generation may be the fertile soil of a succeeding one. The knowledge that the leguminous plants derive a portion of their nitrogen from the atmosphere has not up to the present time been of much practical advantage to the farmer; while it was still only an idea, he had already made use of it as far as it would go. We have shown upon our rotation ground where no leguminous crop has been allowed to grow, the violent efforts made by the trefoil to establish itself there. Upon the field which had grown beans until it would grow them no longer, magnificent crops of red clover could be grown; while upon the wheat land, when put out of cultivation, every sort of native herbage has found food suitable to its requirements. What will be the solution of all these problems? Will the day come when seeds are sent out furnished with the appropriate organisms to supply the deficiency in our fields? The last half-century has seen the rise of artificial manures and their establishment upon a secure basis; the next generation must take up a new line of enquiry, and I know none which is likely to lead to more important results, and to be more beneficial to the practical farmer, than an enquiry into the habits of the leguminous plants.

THE LATE PROFESSOR HARKER.

In the last number of the *Gazette* we grieved to mention the very serious illness of Professor Harker: it is with yet greater grief that we now record that the hopes which we ventured to entertain of his recovery and possible return to his beloved work at the College proved vain, and that his death took place at his residence, Oakley Villas, on Wednesday, December 19th, 1894, and the funeral in the Cemetery the following Friday. The Principal conducted the service, and there was a large attendance of the Professors and representatives of the Students and scientific bodies. For some few years his health had caused some anxiety, but with characteristic courage he battled bravely with his

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